# Forward jets and forward-central jets at CMS

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**Abstract.** A measurement of the cross section of inclusive forward jets in proton-proton collisions at $\sqrt{s} = 7$ TeV at CMS experiment, based on a data sample collected in 2010 and corresponding to an integrated luminosity of 3.14 pb$^{-1}$ is reported. Jets are reconstructed with the anti-kT (R=0.5) algorithm in the Hadronic Forward (HF) calorimeter at pseudorapidities $3.2<|\eta|<4.7$, in the transverse momentum range $p_T$ = 35-140 GeV/c. The single differential cross section as function of the jet transverse momentum is presented and compared to next-to-leading order perturbative QCD calculations, PYTHIA and HERWIG parton shower event generators, as well as to the CASCADE Monte Carlo.
In addition, a measurement of dijet production with one jet in the forward region ($3.2<|\eta|<4.7$) and one jet in the central region ($|\eta|<2.8$) is presented. Differential cross sections are obtained as function of the transverse momentum of the jets. The measurements are compared to perturbative QCD calculations, PYTHIA and HERWIG parton shower event generators, as well as by the CASCADE Monte Carlo.

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## INTRODUCTION

Jet production in hadron-hadron collisions is sensitive to the underlying partonic QCD processes, to the details of parton radiation and to the parton density functions (PDFs) of the colliding hadrons. At previous colliders, the measured jet cross sections at large transverse momenta are successfully described by perturbative QCD calculations over several orders of magnitude [1, 2]. The measurements, however, are limited to central pseudo-rapidities $|\eta|<2.4$, where the momentum fractions $x_1$, $x_2$ of the incoming partons are of the same order. Jets produced in the forward (or backward) hemispheres result from scatterings between colliding partons with increasingly different momentum fractions $x_1 \ll x_2$ , and thus allow one to study QCD in the small-x region where PDFs are less well constrained by DIS data, and where deviations of the parton dynamics beyond the standard DGLAP evolution e.g. of the BFKL, CCFM or saturation types are expected. Additionally, beyond the QCD motivation, jet measurements in the forward region are of interest for vector-boson-fusion processes where a Higgs boson can be produced in conjunction with forward and backward jets.
A measurement of the cross section of inclusive forward jets in proton-proton collisions [3] and of the production of forward jet in conjunction with a central jet [4] using the early data collected by the Compact Muon Solenoid (CMS) detector at the LHC during 2010, corresponding to 3.14 pb$^{-1}$ of integrated luminosity, with proton-proton collisions at a center of mass energy of 7 TeV, is presented.

## THE CMS DETECTOR

The Compact Muon Solenoid [5] is one of two general-purpose particle physics detectors built at the Large Hadron Collider at CERN. The detector has been designed to study various aspects of proton-proton collisions. To enhance the physics reach of the experiment, the CMS subcomponents must provide high-precision measurements of the momentum and the energy of collision products. The CMS detector comprises the tracking system covering the pseudo-rapidity range -2.5$< \eta <$2.5 and the calorimetry system covering the pseudorapity range -5$< \eta <$5. The forward region (2.9$< |\eta| <$5.2) is covered by the hadronic forward calorimeter (HF) which consists of iron absorbers with embedded radiation hard quartz fibres, located at 11.2 m from the interaction point on both sides of the experiment.

## INCLUSIVE FORWARD JET PRODUCTION CROSS SECTION

The infrared and collinear safe anti-k$_T$ (R=0.5) jet clustering algorithm [6] is used to reconstruct all jets starting from energy deposits in the calorimeters [7]. The jets are required to be well contained within the fiducial acceptance, i.e. with their reconstructed axis within 3.2$< |\eta| <$4.7. Various jet quality cuts are applied to remove unphysical energy deposits.
To obtain the jet cross section for the hadronic final state (i.e. fully corrected for the detector reconstruction effects) a bin-by-bin correction is calculated from the simulated samples. The number of jets $N_{\text{jets}}$ are binned in transverse momentum (p$_T$) and pseudorapidity ($\eta$) and the differential inclusive jet cross-section is obtained as $\frac{d^2\sigma}{dp_T d\eta} = \frac{C_{\text{unfold}}}{\mathscr{L}} \cdot \frac{N_{\text{jets}}}{\Delta p_T \cdot \Delta\eta}$, where $C_{\text{unfold}}$ is the detector-level to hadron-level correction factor accounting for bin-by-bin migrations due to resolution effects, $\Delta p_T$ and $\Delta\eta$ are the bin widths in p$_T$ and $\eta$.
In all p$_T$ bins of the measured cross section, the systematic uncertainty is dominated by the accuracy of the jet enegy scale (JES). Both experimental sources of uncertainties and theoretical ones have been considered. The fully corrected jet cross section as a function of p$_T$ is shown in Figure 1, on the left, compared to all the theoretical models considered. The total experimental systematic uncertainty is shown as a yellow band. Figure 1, on the right, shows the fractional difference between the experimental jet cross-section and the theoretical predictions. The predictions agree reasonably with the measurements within the theoretical and experimental uncertainties.
A reduction of the experimental uncertainties, mostly the jet energy scale, is needed in order to extract more precise conclusions from the data-theory comparison.

## CROSS SECTION MEASUREMENT FOR SIMULTANEOUS PRODUCTION OF A CENTRAL AND A FORWARD JET

The differential production cross section of forward jet in conjunction with a central one is measured with respect to $\eta$ and p$_T$ of the two jets separately. Jet clustering algorithm and widths in the p$_T$ spectrum are the same of the inclusive analysis. The

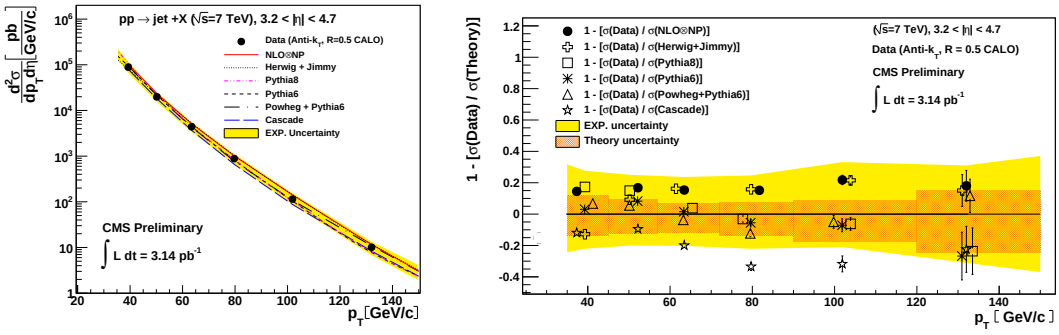


**FIGURE 1.** Inclusive jet cross section measured at forward pseudorapidities 3.2< $|\eta|$ <4.7 fully corrected and unfolded, compared to various hadron-level theoretical predictions (on the left). Fractional differences between forward jet spectra measured and theoretical predictions (on the right). Points have been slightly displaced to the right and left for visibility purposes. The error-bars on the data points show statistical uncertainties. The error bands represent the systematical and theoretical uncertainties.

forward and central regions are defined respectively as $|\eta|$ <2.8 and 3.2< $|\eta|$ <4.7. An event is accepted if there is at least one reconstructed jet with axis within each one of the pseudorapidity ranges with transverse momentum $p_T > 35$ GeV. If more than one jet is present in the central or forward region, the one with the highest $p_T$ is considered.
To obtain the jet cross section for the hadronic final state a bin-by-bin correction is calculated from several simulated samples, which have been reweighted at hadron level to match the measured data distributions. As for the inclusive analysis the major source of uncertainty is the jet energy scale.
The fully corrected cross section for simultaneous production of at least one central and at least one forward jet is measured as a function of the forward and central jet $p_T$. To better evaluate the compatibility of the Monte Carlo predictions with the measured cross section, the ratio of the data over various Monte Carlo simulations are plotted in Figure 2 on top of the band corresponding to the total uncertainty . The uncertainty bands take into account both the statistical and the systematic errors, summed in quadrature. The HERWIG MC event generator, which uses angular ordering for the showering, describes the data best. The others MC event generators, with different tunes, do not describe the data well over the full $p_T$ range.

## CONCLUSIONS

We have measured forward jet production in the pseudorapidity range 3.2< $|\eta|$ <4.7 and the cross section for the production of one central and one forward jet with the CMS detector using 3.14 pb$^{-1}$ of proton-proton collision data collected at $\sqrt{s}$ =7 TeV.
Within the current experimental and theoretical uncertainties, perturbative calculations reproduce globally well the measured inclusive forward jet cross section, while the data-model comparison shows that some calculations of the production of one central ($|\eta|$ <2.8) and one forward jet (3.2< $|\eta|$ <4.7) are not in agreement with data.
Both the measurement provides a first test of perturbative QCD calculations in the forward region at the highest energies ever, as well as a first cross-check for QCD back-

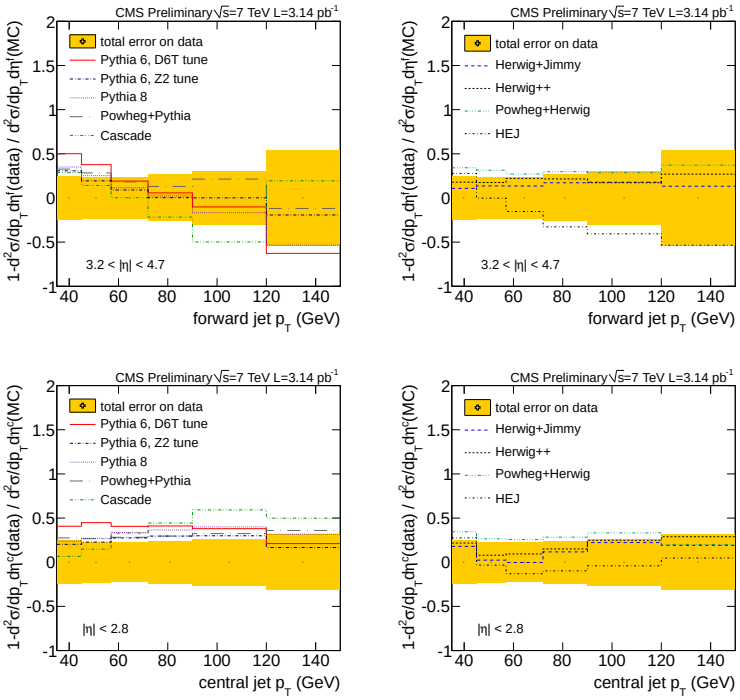


**FIGURE 2.** Ratio of the fully corrected $p_T$-differential jet cross section for the forward and the central region in data over the various Monte Carlo models considered.

ground estimates of other scattering processes, such as vector boson fusion, characterized by forward/backward jet production.

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